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STUDIES ENERGY HARVESTING WITH THE HELP OF SMART AND NANO-ANTENNA

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ABSTRACT

We are living in a modern era of science and technology. There is an urgent need to search for alternative energy sources in the 21st century. Rising costs of carbon-based fuels coupled with increased emissions have placed a greater demand on the clean energy sector. Recently, renewable energy has made up of high contributions to power generation without increasing environmental pollution. The energy source is photovoltaics (PVs), which have traditionally been made of high-purity, expensive crystalline silicon (c-Si). In addition, PV solar cell-based devices are designed to absorb solar energy in the visible region 0.4 µm-1.4 µm which constitutes 51% of the solar spectrum. Therefore, the search for cheaper, high-performance materials for solar cell-based applications is mandatory.

KEYWORDS: PVs, C-Si, IR, Rectenna, MIM, ONAS, D-SINWS

INTRODUCTION

The primary goal is to increase solar energy harvesting through the use of optical antennas, particularly in the infrared (IR) region of the electromagnetic spectrum. Optical antennas can be fabricated using either metallic nano-particles or semiconductor nano-wires. This categorizes optical antennas into two main types: metallic nano-antennas (rectennas) and semiconductor nano-antennas. When an electromagnetic wave impinges upon an optical antenna, it induces a time-varying current on the antenna's surface, resulting in the generation of voltage at the antenna's feeding point. The generated voltage oscillates at the frequency of the incident wave. To obtain Direct Current (DC) power, a rectifier is necessary at the antenna's feed point. Such systems are commonly referred to as "rectennas" and are used to convert received signals into DC power, thereby producing electricity. The text mentions an infrared rectenna structure based on metal-insulator-metal (MIM) diodes between dipoles, designed to operate at a specific wavelength (λ-10 µm). However, the efficiency of this system was reported to be less than 1%, indicating a need for significant improvements. The introduction briefly highlights previous research efforts in the field. For instance, there's mention of a spiral nano-antenna designed for solar energy harvesting in the mid-infrared region. Additionally, a monopole antenna based on nickel for the reception of thermal radiation is discussed. Researchers have also introduced upper-efficiency bounds for metallic nano-antennas, with silver showing high efficiencies near or above 90%. Despite the promise of metallic nano-antennas in terms of their high efficiency over a wide frequency range, the text suggests that there is a lack of suitable rectifier diodes described in the literature that can meet the requirements of solar energy harvesting

METHODOLOGY & RESULT

Semiconductor nano-antennas have recently gained tremendous interest due to their light absorption. Light absorption in standing semiconductor nanowires is a complex phenomenon, with a strong dependence on nano-wire dimensions, lattice arrangement, and absorption coefficient of the raw materials. Ordered semiconductor nano-antenna structures can be fabricated through a few unattractive methods, such as lithography and polystyrene ball assembly, due to their high cost and complexity.

The suggested ONAS system enhances the absorption efficiency spectra, which indicates that it can capture more incident electromagnetic energy compared to a conventional dipole antenna. The absorption efficiency has been improved by at least 15%, suggesting that ONAS can effectively capture and convert incoming light or electromagnetic waves. The absorbed power profiles of the ONAS system are enhanced, implying that it can accumulate more power from the incident radiation. This increase in absorbed power is likely due to the improved absorption efficiency mentioned earlier. The emission patterns, or how the ONAS system re-emits energy, are improved. This might indicate that the ONAS system can efficiently re-emit energy or transmit it to another component or system. The ONAS system offers a broader bandwidth compared to traditional systems, operating efficiently in the wavelength range from 450 nm to 1400 nm. This wide bandwidth makes it suitable for a variety of applications and allows it to capture a wide range of electromagnetic wavelengths. At a specific wavelength of $\lambda = 500$ nm, where sunlight irradiance is at its maximum, the flower-shaped dipole nano-antenna in the ONAS system demonstrates a remarkable efficiency of 74.6%. This is significantly higher than the efficiency of conventional solar cells. The text mentions that the calculated ultimate efficiency of a structure called D-SINWs (presumably part of the ONAS system) with a solid semiconductor core is 19.3%. This ultimate efficiency can be further improved by adjusting the geometric parameters of the D-SINWs or by using a hybrid core. Using a hybrid core in the D-SINWs structure results in an ultimate efficiency of 32.62%, which is a substantial improvement over the solid semiconductor core. This suggests that the choice of core material is critical for optimizing the performance of the ONAS system. By fine-tuning the design of the D-SINWs, an

even higher ultimate efficiency of 38% can be achieved. This demonstrates that the system's performance can be optimized through design adjustments.

Metallic Nano-Antenna: Solar energy with the solar spread as shown in Figure 1(a) is considered the most significant source of green renewable energy. According to the figure noted that solar energy oscillates over a wide range of wavelengths. Most of this energy is concentrated in the visible, whereas a small amount is distributed over the ultraviolet and infrared. Photovoltaic (PV) solar cells absorption performance is mainly limited by the problem of semiconductor band gap. Figure 1(b) shows the absorption coefficients and absorption bands of major semiconductor materials. Important things of this figure that the silicon as an examplecannot absorb light energy more than 1100 nm due to the silicon band gap of 1.1 ev at room temperature. In spite of the developed industry of PV solar cells, the solar cells conversion efficiency doesn't exceed 30%.

The approaches to PV solar cells with higher efficiency for energy conversion is rectenna. Figure 2 shows a schematic block diagram of the "rectenna" system with load. As illustrated in Figure 2, a rectenna system includes a metallic nano-antenna, a rectifier diode, and a DC pass filter all in parallel. In addition, the load must be included in the scheme because it may affect the output voltage and the rectenna efficiency. The rectifier diode is an Ultra-high-Speed diode that converts AC power to DC power. The conversion efficiency of the diode is a key factor in the rectenna performance. The DC pass filter is present to smooth the signal before delivery to the load.

A metallic nano-antenna is a light coupling device that collects solar energy in the optical frequencies band for generating electricity with high-efficiency conversion. It consists of nano-meter-scale metallic particles mounted on the substrate as shown in Figure 3 (a). Currently, investigated optical nano-antennas include various designs in terms of different material constitutions, configurations, and arrangements.

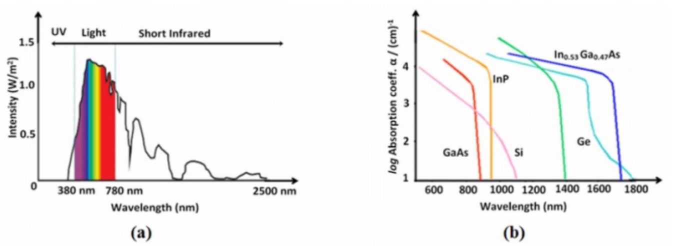


Figure 1 (a) Solar energy spectrum of the sun, (b) Bandgap of common semiconductor materials

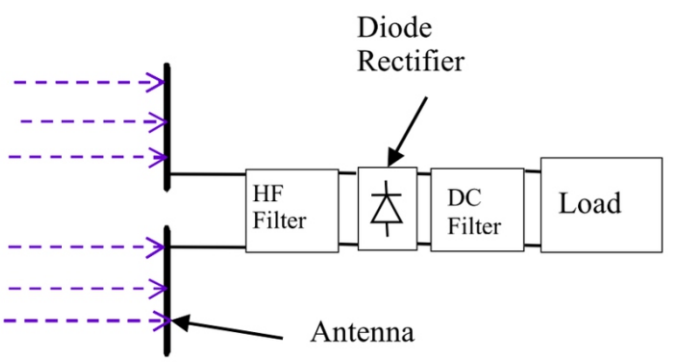
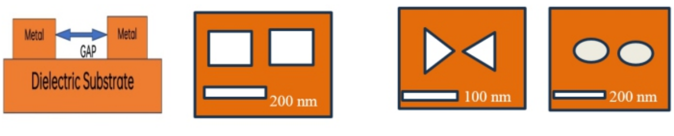


Figure 2 Schematic diagram of the rectenna system.

Figure 3 (b) shows three common configurations for the metallic nano-antenna such as rectangular, bowtie, and elliptical shapes. The interaction between surface plasmons of metallic nano-particles induced by light is capable of focusing and confining visible and near-infrared (NIR) lights into nano-meter scale dimensions and this will be explained in detail in the following subsections. Nano-antennas based on surface plasmons can be used for many applications, such as antennas for nano-scale imaging and spectroscopy and for improving solar cell efficiency. The scope of our research is to use the nano-antennas for energy harvesting applications.Rectenna in principle has no efficiency limitations since the major problem of semiconductor band gap does not apply here. Efficient collection by the antenna, perfect matching between the diode and antenna, and efficient rectification nominate rectenna to have a theoretical conversion efficiency of 100%. Besides the advantage of higher efficiency for energy conversion of rectennas, Table 1. shows many other better aspects as compared to the traditional solar cells. As indicated by the table, rectennas can operate during the whole day and independently of weather conditions such as humidity and cloud cover compared with traditional solar cells that operate during the daytime only and require clear and dry weather. On top of that, unlike solar cells' operation, rectennas radiation, being isotropic in nature, does not require a certain orientation for energy collection. Further, rectennas can be fabricated on substrates much cheaper than silicon. In addition, rectennas could be used to cool buildings and other structures, transforming the once-wasted heat into electrical energy.

Several technical challenges have faced the THz rectenna devices such as the design, simulation, and creation of nano-antennas. Due to very small geometric features, the simulations of the nano-antennas require great computational resources. Nano-antennas materials should also be selected with proper optical and electrical characteristics in the THz range. In addition, the Nano-antennas fabrication process needs advanced machines like electron beam lithography. The design and construction of THz diode with high conversion efficiency from AC to DC are also challenging problems for THz rectennas. The growth of the nanometer oxide layer needs an accurate and precise fabrication process. Furthermore, the MIM diode has very high input impedance with high mismatching between the diode and nano-antennas. Finally, the MIM diode exhibits a considerable parasitic capacitance.



(a) (b)

Figure 3 Metallic nano-antenna (a) Side view, (b) Top views for common antenna configurations

Objectives	Solar cell	Rectenna
Operation time	Day time only	Whole day
Weather conditions	Requires clear and dry weather	Independent of weather conditions
The theoretical efficiency of conversion	Low	High
Orientation sensitivity	Very sensitive	Less sensitive
Absorption band	Limited absorption	Wide range absorption
Cost	High	Low

Table- 1, Shows the comparison between the traditional Solar cell and Rectenna.

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